1972

Final report on research project unsymmetrical plate girders, November 1971 (Revised May 1972)

Alexis Ostapenko

Unsymmetrical Plate Girders

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FINAL REPORT ON RESEARCH PROJECT
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This work was conducted as part of the project Unsymmetrical Plate Girders, sponsored by the American Iron and Steel Institute, the Pennsylvania Department of Transportation, the Federal Highway Administration of the U. S. Department of Transportation, and the Welding Research Council. The opinions, findings and conclusions expressed in this report are those of the authors and not necessarily those of the sponsors.

Department of Civil Engineering
Fritz Engineering Laboratory
Lehigh University
Bethlehem, Pennsylvania

November 1971
(Revised May 1972)

Fritz Engineering Laboratory Report No. 328.16

328.16
November 1971
(Revised May 1972)

FINAL REPORT FOR RESEARCH PROJECT
UNSYMMETRICAL PLATE GIRDERS

by

Alexis Ostapenko[1]

ABSTRACT

A three year research program was conducted on the ultimate static strength of unsymmetrical plate girders. A general theoretical approach was established for transversely stiffened plate girders and then extended to longitudinally stiffened girders. The theory was confirmed by testing full-scale girder specimens. Formulas for designing transversely stiffened plate girders (symmetrical, unsymmetrical, hybrid) on the basis of ultimate strength were developed. This report states the original project objectives, summarizes each technical report as describing a specific phase of the project, gives recommendations on the implementation of the obtained results, and presents suggestions for future research.

CONTENTS

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1 Professor of Civil Engineering, Fritz Engineering Laboratory, Department of Civil Engineering, Lehigh University, Bethlehem, Pennsylvania.

1. INTRODUCTION --- PROBLEM STATEMENT

An unsymmetrical plate girder is defined as a girder whose cross section is symmetrical about the axis lying in the plane of the web, but unsymmetrical about the centroidal axis perpendicular to the web. The most obvious examples are the composite girders and girders in bridges with orthotropic plate deck. The need for research on unsymmetrical plate girders arose from the fact that the specifications and design procedures currently available to designers did not specifically cover unsymmetrical sections except for the consideration of the stresses computed according to the ordinary beam theory. The formulas for web buckling and the ultimate strength were developed for symmetrical girders and it was apparently assumed that they should be equally applicable to unsymmetrical sections. However, this is not always true. For example, composite beams in the positive moment area tend to be overdesigned and the panels with an orthotropic deck in the area of a negative moment such as at an intermediate support in a continuous or cantilever girder are underdesigned. The latter applies, in general, to sections which have the compression flange smaller than the tension flange.

Another reason for the need of an ultimate strength study on unsymmetrical plate girders was that no study had been performed on plate girder panels subjected to a combination of high moment and high shear -- the case of particular importance again at an intermediate support of a continuous or a cantilever girder. It was thus desirable to develop a comprehensive analytical approach for the ultimate strength of plate girders subjected to any combination of shear and moment.

Financial support for this research was solicited and obtained from the American Iron and Steel Institute, the Pennsylvania Department of Transportation, the Federal Highway Administration of the U.S. Department of Transportation and the Welding Research Council. Technical guidance was provided, in addition to the sponsors, by the Welded Plate Girder Subcommittee of the Welding Research Council and by its Task Group on Unsymmetrical Plate Girders. The members of these two groups are listed in Appendix 3. The individuals engaged on the project are listed in Appendix 2.

The research program included experimental and theoretical work and resulted in a set of formulas for designing transversely stiffened plate girders and in a method for analyzing longitudinally stiffened girders (computer must be used in the latter case). In the forthcoming chapters, the following items are summarized: the objectives (Ch.2), research findings (Ch.3), recommendations for implementation (Ch.4), and recommendations for future research (Ch.5).

2. OBJECTIVES AND OUTLINE OF RESEARCH PROGRAM

As stated in the first proposal (Reports 328.1A to 328.1C), the ultimate objective of this research was

the development of guide lines for design rules for unsymmetrical plate girders used in highway bridges.

This ultimate objective was intended to be attained by performing the following phases of research:

(1) Investigation of static ultimate strength.

(2) Determination of the behavior of unsymmetrical plate girders, in particular, the behavior of the web.

(3) Correlation of the behavior of unsymmetrical girders with fatigue studies on symmetrical girders.

(4) Formulation of guide lines for design rules.

The ultimate objective was met as described in Reports 328.12 and 328.10 (see Chapter 3) and in Chapter 4. Although the phases (1) to (4) were carried out in general, the scope, emphasis, and timing were modified during the course of research as clarified by the immediate objectives stated in the proposals for each contract year.

Objectives for the Period 1966-67 (Report 328.1C, page 10)

1. Exploration of new theoretical approaches that will take into consideration those aspects of unsymmetrical girders (geometrical and loading) to which the methods valid for symmetrical girders are not applicable.

Comments: This objective was met and exceeded by developing analytical models for the ultimate strength of unsymmetrical plate girders subjected to pure shear or pure bending. The case of combined forces needed further work as well as information from the planned pilot tests on the behavior of girder panels.

2. Planning and carrying out of one or two pilot tests to verify the methods developed analytically and/or to obtain better insight into the girder behavior in order to arrive at more rational methods of analysis.

Comments: Instead of one or two, eight tests on three girders were designed and prepared. However, the actual testing had to be extended into the next contract period due to some complications with testing equipment.

Objectives for the Period 1967-68 (Report 328.2, page 1)

1. Completion of the studies on the static ultimate strength. This will include: the evaluation of the pilot tests conducted during 1966-67, the development of tentative design criteria based on the ultimate strength and their verification with tests on full-scale plate girder specimens.

Comments: The pilot tests carried over from the previous period were completed and evaluated and a report was prepared (Rept. 328.5). The results were used to refine the first version of the theory and to extend it to the case of combined forces. Two full-scale plate girders, one of them longitudinally stiffened, were designed according to the new theory and tested (Rept. 328.6). Only limited work could be done on design methods since the pilot tests required more time than originally anticipated.

2. Analytical study of the strain distribution and the variation of curvature in the web for one cycle of loading. This study will be correlated with experimental observations on test specimens.

Comments: This objective was proposed in anticipation of utilizing results of a related study conducted on another project at Lehigh

(B.T. Yen's). As unsurmountable difficulties were encountered in analytical work by both projects, the work was modified to study the strain distribution and curvature changes as observed in the tests. A computer program was developed for this purpose and web deflection contour maps, and stress distribution patterns were presented in the test reports (328.5 and 328.6).

3. Analytical study of the effect of longitudinal stiffeners on the strength and behavior of unsymmetrical plate girders.

Comments: The theory was extended to longitudinally stiffened girders. The tests (Rept. 328.6) confirmed its validity. (Note that this item was added to the original objectives of the project).

Objectives for the Period 1968-69 (Report 328.4, page 2)

1. Evaluation of the test results from the two full scale test specimens of the preceeding contract period (1967-78). The results will serve as the basis to modify, if necessary, the theoretical approach to the ultimate strength of longitudinally stiffened plate girders. A report on the full scale tests will also be prepared.

Comments: The report on the full scale tests was actually completed ahead of time during the previous period 1967-68. The theories for transversely and longitudinally stiffened girders were refined and a report on them prepared (Rept. 328.11), also see Comments to item 4 below.

2. Completion of the studies in the areas of fatigue and longitudinal stiffeners.

Comments: Longitudinal stiffeners were dealt with under item 1. The fatigue study culminated in Report 328.15 which gave recommendations for preventing development of fatigue cracks due to lateral flexing of the web plate.

3. Completion of the design recommendations.

Comments: Design recommendations for transversely stiffened plate girders, in the form of formulas suitable for manual computations, were developed and described in a preliminary report which was distributed to the Subcommittee members and sponsors in early September 1969 (Rept. 328.12 - prelim.). The method for longitudinally stiffened girders still requires the use of a computer.

4. Preparation of reports for publication and of the final report.

Comments: All the planned reports were drafted, but not all produced, before the contract period terminated in September 1969. The following reports were then still at various stages of production (typing, drawing, revisions, editing, minor additional computations): 328.8 to 328.10, 328.12 and 328.16. Due to other commitments, their completion was delayed till 1970 and early 1971 (See Appendix 1 for the list).

3. RESEARCH FINDINGS --- SUMMARIES OF TECHNICAL REPORTS

Research conducted to meet the stipulated objectives is described in a series of technical reports.* Brief summaries of these are given below in logical groups.

3.1 Static Tests on Unsymmetrical Plate Girders

328.5 Dimitri, J. R., and Ostapenko, A.
PILOT TESTS ON THE ULTIMATE STATIC STRENGTH OF UNSYMMETRICAL PLATE GIRDERS, June 1968.

Eight tests on three transversely stiffened unsymmetrical plate girders subjected to shear, bending or a combination of shear and bending were conducted to explore experimentally the modes of the ultimate strength behavior. Of particular interest were the panels under high moment and high shear since no tests on such panels had been conducted in previous research. Results of these tests served to facilitate the formulation of a theoretical approach. For example, on the basis of a comparison of test observations with some sample calculations it was concluded that the elastic restraint of the web plate by the flanges and stiffeners can be much better approximated by assuming the web plate to be fixed at the flange and simply supported at the stiffeners rather than simply supported at all edges as has been assumed by other researchers and used by specifications. Another purpose of these tests was to develop a methodology for testing such girders efficiently.

*A complete list of the reports and of other items assigned report numbers is given in Appendix 1.

328.6 Schueller, W., and Ostapenko, A.
STATIC TESTS ON UNSYMMETRICAL PLATE GIRDERS - MAIN TEST SERIES, September 1968.

Six tests on a transversely stiffened unsymmetrical plate girder and six tests on another identical girder except for an added longitudinal stiffener were performed. These specimens were designed on the basis of the theory evolved with the help of the pilot tests (Report 328.5). All panels were subjected to various combinations of shear and bending so that the validity of the theory could be checked throughout the range. Readings of the lateral web deflection were made for a later study of the fatigue strength (Rept. 328.15). The important findings were:

(1) Theory for both types of girders was confirmed. Of particular importance this was for the longitudinally stiffened panels under combined forces (moment and shear) for which neither tests nor theory had been available.

(2) Previously recommended rules for design of the end post are unsafe since the tension field pull was assumed to be distributed uniformly over the depth whereas, in reality, it is concentrated over the top portion and thus subjects the end post to a substantially greater shear.

(3) The technique of using diagonal tension bars as temporary reinforcement for test girder panels was very satisfactory.

3.2 Ultimate Strength Theory for Transversely and Longitudinally Stiffened Plate Girders (Symmetrical and Unsymmetrical)

328.7 Chern, C. and Ostapenko, A.
ULTIMATE STRENGTH OF PLATE GIRDERS UNDER SHEAR, August 1969.

The theory for transversely stiffened plate girder panels subjected to pure shear was derived and compared with all the test results from this project and from the publications available at the time.

Although the theory was found to agree with tests better than theories proposed by other investigators, it is not convenient for design use since it requires lengthy iterative calculations which cannot be performed efficiently without a computer.

328.8 Chern, C., and Ostapenko, A.
BENDING STRENGTH OF UNSYMMETRICAL PLATE GIRDERS, September 1970.

The method described in this report was developed with the aim of not only giving a more accurate means of determining the ultimate strength of girder panels subjected to bending than offered previously by others, but also with the aim of providing an analytical approach which could be extended to the case of combined forces (shear and bending). The formulation obtained is not as time-consuming in solving as that for shear, but the use of a computer is still desirable. Comparison of the theoretical results with all available tests showed a good agreement of the ultimate loads and of the modes of failure.

328.9 Chern, C. and Ostapenko, A.
UNSYMMETRICAL PLATE GIRDERS UNDER SHEAR AND MOMENT, October 1970.

The theories of shear and bending strengths (Repts. 328.7 and 328.8) were generalized and combined into one to be able to analyze panels of transversely stiffened plate girders under any combination of shear and bending. The theory thus developed agreed favorably well with the available 53 tests on symmetrical, unsymmetrical, homogeneous and hybrid plate girders. The whole range from compact beams to girders with very slender webs was covered. It could hardly be expected that an analysis of such a complex problem could be simplified to a form readily manageable by manual calculations, but it was expected that numerical data could be generated for developing a simplified method (see Rept. 328.12).

328.10 Ostapenko, A., and Chern, C.
STRENGTH OF LONGITUDINALLY STIFFENED PLATE GIRDERS UNDER COMBINED LOADS, December 1970.

The theory developed in Rept. 328.9 for transversely stiffened plate girders was extended to plate girders with one longitudinal stiffener in addition to transverse stiffeners. It was necessary to enforce compatibility of deformations between the web subpanels. Nineteen test results were available for the verification of the accuracy of the method. The average agreement was within 4%. Probably the most remarkable result of this study was the observation that the addition of a longitudinal stiffener gives the greatest increase of the ultimate strength under the combination of high moment and high shear rather than under shear or moment alone.

328.11 Chern, C.
ULTIMATE STRENGTH OF TRANSVERSELY AND LONGITUDINALLY STIFFENED PLATE GIRDERS, August 1969 (Ph.D. Dissertation).

This report represents the doctoral dissertation of C. Chern and describes the theories of Repts. 328.7 to 328.10 at their stage of development before the final refinements. Thus, parts of this report served as drafts for Reports 328.7 to 328.10.

3.3 Design Formulas

The ultimate strength theory described in the above reports had to be simplified to make it suitable for use in practical design. The major effort was to develop formulas amenable to manual calculations. This work was completed for transversely stiffened plate girders and the results are presented in Report 328.12 below. However, neither time nor funds were available to accomplish this for longitudinally stiffened girders.

328.12 Ostapenko, A., Chern, C., and Parsanejad, S. STRENGTH FORMULAS FOR DESIGN OF STEEL PLATE GIRDERS, January 1971.

Formulas for the determination of the ultimate strength of transversely stiffened plate girders subjected to any combination of shear and bending are derived in this report. These formulas are based on the numerical output from the computer programs of the theories of Reports 328.7, 328.8 and 328.9 and are suitable for manual computations. Included are also some special considerations of practical design --- girders without intermediate transverse stiffeners and dimensional limitations to preclude the deleterious effect of fatigue due to the back-and-forth deflection (see also Report 328.15) of the web plate. A numerical example is given to demonstrate the step by step procedure of the application of the formulas.

3.4 Fatigue Studies

328.15 Parsanejad, S., and Ostapenko, A. FATIGUE STRENGTH OF UNSYMMETRICAL PLATE GIRDERS, May 1970.

Web deflections from the static tests (Rept. 328.6) were used to compute the stresses in the web due to the flexing accompanying repeated load application. These stresses were correlated with the S-N curve previously obtained from fatigue tests to establish a limitation for the web slenderness. This limitation is recommended for use in Report 328.12. Other significant items are: the formulation of a method for analyzing stresses from deflections, and a discussion of the effect of initial deflections and of an overload on the fatigue life of a plate girder.

4. RECOMMENDATIONS FOR IMPLEMENTATION OF RESEARCH FINDINGS

The formulas proposed in Report 328.12 give the ultimate strength of plate girders and thus can be directly used in a load factor design method, such as recommended in the AASHO Interim Specification for Highway Bridges (1970-71). Besides greater economy and reliability, these formulas will provide a means for designing girders without intermediate transverse stiffeners. However, some simplifications may be desirable before incorporating these formulas into a specification as described under Item 4 of Recommendations for Future Research (Chapt.5).

The proposed formulas can be also used in an allowable stress approach. An allowable stress in this case is the result of dividing the corresponding ultimate strength by a suitable factor of safety and by the pertinent cross-sectional constant, for example,

$$F_v = \frac{V_u}{(FS)(A_w)} \quad \text{and} \quad F_b = \frac{M_u}{(FS)(S)}$$

This approach is analogous to the one incorporated into the present AISC Specification.

The intended factor of safety in the AASHO Specification is FS = 1.80. However, the actual value varies considerably depending on many parameters which are not directly considered in the specification, but affect the girder strength, such as, the location of the centroidal axis in a panel under moment and shear. A limited study (Item 328.1 C of Appendix 1) showed, for example, that, under certain conditions of geometry and loading, the real factor of safety may be barely over 1.0. Ultimate strength formulas provide a means for eliminating such inconsistencies. Assuming that typical plate girder bridges rarely have spans shorter than 80 feet and utilizing the concepts described in "Tentative Criteria for Load Factor Design of Steel Highway Bridges" by G.S. Vincent (AISI Bulletin No. 15, March 1969, pages 21 to 23), a factor of safety equal to 1.66 can be recommended.

When applicable, the resultant allowable stresses should be multiplied by the AASHO amplification factors for various load combinations.

The stiffeners may be safely proportioned according to the rules of the AASHO Interim Specifications of 1971.

5. RECOMMENDATIONS FOR FUTURE RESEARCH

Two groups of recommendations for future research are made here in connection with this research project:

1) Extension of Project: items directly related to the project which will serve to complete, extend, refine and facilitate implementation of the results obtained.
2) New Areas: items in which the findings and theories of the project can be utilized or new items pertinent to the research area.

1. Tests on composite transversely stiffened plate girders. Although the theoretical formulation of the method as well as the design formulas (328.12) should be applicable to composite plate girders, there are no experimental results to confirm this. High rigidity and cracking of the concrete slab may indicate that its effect on the panel strength is of a different nature than that of a metal flange. It would, thus, not be prudent to apply the theory till some tests on composite plate girders have been conducted. Yet, this is the type of girder for which the greatest gain in economy through the acceptance of the proposed method is expected.

2. Preparation of a report on computer programs. Several computer programs were written for obtaining numerical results according to the method developed on the project. However, neither time nor funds were sufficient to adequately document them so that they could be utilized by other researchers or in a design office. It would be desirable to prepare a report for this purpose.

3. Development of design formulas for longitudinally stiffened plate girders. The theoretical approach developed by the project for longitudinally stiffened girders gave good agreement with test results and thus can be accepted as a reliable design tool. However, it is too complicated for manual computations. Similar difficulty was encountered for transversely stiffened girders, and a set of formulas were developed from the numerical output of a computer program based on the method (Rept. 328.12). It is recommended that an analogous operation be carried out for longitudinally stiffened plate girders thus leading to a ready and wider implementation of the theory.

4. Inclusion of axial load, and refinement, simplification and classification of design formulas. It is recommended that the design formulas for transversely stiffened girders be generalized to include the effect of an axial tension or compression. Although the formulas in their present form (Rept. 328.12) can be used for the case of an axial load by a competent designer who understands

the concepts of the method, more explicit formulation will considerably aid in their general implementation. As new test results have become available after the completion of the project, it would be desirable to refine the formulas, particularly in the range of low b/t where the web buckles inelastically. Since the design formulas (328.12) cover girders with very compact to very slender webs, considerable practical simplification of the formulas can be made if they are separated into some specific ranges of classification, such as, beams, intermediate depth girders, deep girders

5. Design of transverse stiffeners. A study is needed of the transverse stiffener requirements on the basis of the proposed analytical model; the rules proposed by other research projects were accepted as giving stiffeners of adequate strength but they may be too conservative.

6. Design of end panels and end posts. The present recommendation is to design the panel at the end of the girder only for its buckling strength. Additional research is needed to justify utilization of its post-buckling strength and thus making the girder more economical. This will also provide a more accurate approach for designing the end post.

New Areas of Research

7. Plate girders with longitudinal but no intermediate transverse stiffeners. Considerable saving in fabrication costs can be gained from using a longitudinal stiffener instead of transverse stiffeners for girders of intermediate b/t (approximately in the range of b/t = 100 to 200).

8. Multiple longitudinal stiffeners. Very deep plate and box girders become more economical if multiple longitudinal stiffeners are used. At present, only buckling criteria, usually according to the German rules, are employed for designing such girders. Extension of the ultimate strength theory

developed on this project to such girders would be desirable.

9. Plate girder panels of variable depth under bending, shear and axial load (haunched and rigid frame panels). This is a very important and urgent problem since, although such panels are encountered quite often, at present, no reliable means are readily available for analyzing and designing them. Elastic stress and buckling analysis can be possibly performed using a finite element formulation, but this would give no indication of the true safety margin with respect to the ultimate strength. It should be possible to extend the concepts of the proposed theory to such panels.

10. Ultimate strength of horizontally curved plate girders. The basic concepts of the proposed method can be combined with supplementary considerations and applied to the analysis of horizontally curved plate girders for ultimate strength. It appears that the problem should be very complex for aspect ratios greater than about 0.8.

11. Non-rectangular, multi-cellular and horizontally curved box girders. These areas will require a combination and extension of approaches of item 10 and of the current research on single-cell, rectangular box girders conducted at Lehigh University.

12. Plate girders under concentrated and/or distributed loads applied directly to the flange. Only some scattered research has been conducted on this topic, but no unified, comprehensive design procedure is yet available. Of particular importance this case of loading is for large girders (plate and box) under construction, especially, by the "roll-out" method and for crane girders.

6. ACKNOWLEDGEMENTS

This report was prepared as part of a research project on unsymmetrical plate girders conducted in the Department of Civil Engineering, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania. Dr. David A. VanHorn is Chairman of the Department and Dr. Lynn S. Beedle is Director of the Laboratory.

The author expresses his gratitude to the American Iron and Steel Institute, the Pennsylvania Department of Transportation, the Federal Highway Administration of the U.S. Department of Transportation, and the Welding Research Council for supporting this project. The opinions, findings and conclusions expressed in this report are those of the author and not necessarily those of the sponsors. The author also gratefully acknowledges the technical guidance provided by the Welded Plate Girder Subcommittee of the Welding Research Council under the consecutive chairmanship of Mr. M. Deuterman, E.G. Paulet, and G.F. Fox and by the Task Group on Unsymmetrical Plate Girders under the chairmanship of Mr. C.A. Zwissler and, lately, Mr. L.H. Daniels.

Sincere appreciation is also due Dr. G.R. Jenkins, Director of the Lehigh University Office of Research, for his ever ready assistance and promptness in handling contractual arrangements.

APPENDIX 1: LIST OF REPORTS

F.E.L. Report No.	Author(s), Title, Date	Comments
328.1A,B	Ostapenko, A. Proposal for Research: UNSYMMETRICAL PLATE GIRDERS, Initial Versions, Jan.-June, 1966.	To: PennDOT, AISI, WRC
328.1C	Ostapenko, A. Proposal for Research: UNSYMMETRICAL PLATE GIRDERS (PILOT STUDY), Final Version of 328.1(A,B), 7/25/66.	To: PennDOT, AISI, WRC
328.2	Ostapenko, A. Proposal for Continuation of Research: UNSYMMETRICAL PLATE GIRDERS, Period 1967-68, 1/12/67.	To: PennDOT, AISI
328.3	Ostapenko, A., and Dimitri, J. R. BUCKLING OF PLATE GIRDER WEBS, A STUDY CONDUCTED IN 1966-67, most of the results incorporated into Repts 328.7-11.	Not completed as a report.
328.4	Ostapenko, A. Proposal for Continuation of Research: UNSYMMETRICAL PLATE GIRDERS, Period 1968-69, 8/21/67.	To: PennDOT, AISI
328.5	Dimitri, J. R., and Ostapenko, A. PILOT TESTS ON THE ULTIMATE STATIC STRENGTH OF UNSYMMETRICAL PLATE GIRDERS, June 1968.	Full distrib.*, Published in WRC Bulletin No.156 (Nov.1970).
328.6	Schueller, W., and Ostapenko, A. STATIC TESTS ON UNSYMMETRICAL PLATE GIRDERS - MAIN TEST SERIES, September 1968.	Full distrib., Published in WRC Bulletin No. 156 (Nov. 1970).
328.7	Chern, C. and Ostapenko, A. ULTIMATE STRENGTH OF PLATE GIRDERS UNDER SHEAR, August 1969.	Full distrib., Intend to publish in Proceedings of ASCE.
328.8	Chern, C.,and Ostapenko, A. BENDING STRENGTH OF UNSYMMETRICAL PLATE GIRDERS, September 1970.	Full distrib., Intend to publish in Proceedings of ASCE.

*<u>Full distribution</u> means that the report was distributed to the sponsors, members of the WRC Subcommittee for Welded Plate Girders, and, upon approval by the sponsors, to the libraries of some agencies of the U.S. Government and to interested researchers working in the subject area.

APPENDIX 1: LIST OF REPORTS (Continuation)

F.E.L. Report No.	Author(s), Title, Date	Comments
328.9	Chern, C. and Ostapenko, A. UNSYMMETRICAL PLATE GIRDERS UNDER SHEAR AND MOMENT, October 1970.	Full distrib. Intend to publish in Proceedings of ASCE.
328.10	Ostapenko, A., and Chern, C. STRENGTH OF LONGITUDINALLY STIFFENED PLATE GIRDERS UNDER COMBINED LOADS, December 1970.	Full distrib., short vers. for publications in Proceedings of IABSE Colloquium on Plate Girders (1971).
328.11	Chern, C. ULTIMATE STRENGTH OF TRANSVERSELY AND LONGITUDINALLY STIFFENED PLATE GIRDERS, August 1969 (Ph.D. Dissertation).	Full distrib.
328.12	Ostapenko, A., Chern, C., and Parsanejad, S. STRENGTH FORMULAS FOR DESIGN OF STEEL PLATE GIRDERS, January 1971.	Full distrib. A short version for the Conference on Developments in Bridge Design and Construction, in Cardiff (1971).
328.13	Ostapenko, A., et al. COMPUTER PROGRAMS FOR ULTIMATE STRENGTH OF PLATE GIRDERS, computer programs based on the theories of Reports 328.7 to 328.11, not compiled as a report.	
328.14	Ostapenko, A. Request for Additional Funds: UNSYMMETRICAL PLATE GIRDERS, May 1969.	To: PennDOT
328.15	Parsanejad, S., and Ostapenko, A. FATIGUE STRENGTH OF UNSYMMETRICAL PLATE GIRDERS, May 1970.	Full distrib. Published in WRC Bulletin No. 156 (Nov. 1970).
328.16	Ostapenko A. FINAL REPORT FOR RESEARCH PROJECT UNSYMMETRICAL PLATE GIRDERS, November 1971 (Revised May 1972)	Full distrib.

Notes:

1) Report Nos. 328.1, 2,4,14 are used to designate file nos. of proposals.
2) Report Nos. 328.3 and 328.13 are used to file the results of studies which were conducted and then utilized in other reports, but were not organized into separate reports.
3) Reports 328.5 to 328.12 and 328.15 represent Final Reports on the technical phases of the project.
4) Report 328.16 (this report) gives a general summary of the objectives and results of the project. Note that all technical details are presented in the reports under Note 2.

APPENDIX 2: RESEARCH PERSONNEL

The following individuals have been engaged on this research project. The period of association is indicated in the right column.

Name	Period
Project Director and Principal Investigator:	
Ostapenko, Alexis	7/66 - 9/69
Research Assistants:	
Anderson, Charles E.	8/68 - 1/69
Chern, Chingmiin	9/66 - 8/69
Dimitri, James R.	8/66 - 7/68
Kerfoot, Robert P.	7/67 - 8/67
Parsanejad, Siamak	1/69 - 9/69
Schueller, Wolfgang	2/67 - 9/68

APPENDIX 3: LIST OF MEMBERS OF THE WELDING RESEARCH COUNCIL SUBCOMMITTEE FOR WELDED PLATE GIRDERS AND THE TASK GROUP FOR UNSYMMETRICAL PLATE GIRDERS

CONSECUTIVE CHAIRMEN

M. Deuterman
E. G. Paulet
G. F. Fox

SECRETARY

C. F. Larson

MEMBERS

J. H. Adams
A. Amirikian
L. S. Beedle
L. H. Daniels
J. L. Durkee
E. R. Estes, Jr.
J. A. Gilligan
L. Grover
K. L. Heilman
T. R. Higgins
C. D. Jensen
K. Jensen
H. G. Juhl
R. L. Ketter
M. L. Koehler
K. H. Koopman
W. B. McLean
W. A. Milek
W. H. Munse
J. F. Oyler
E. Pisetzner
E. J. Ruble
F. C. Sankey
J. Vasta
I. M. Viest
G. Winter
C. A. Zwissler

The following members of the WRC Subcommittee for Welded Plate Girders also served on the special Task Group for Unsymmetrical Plate Girders:

MEMBERS OF THE TASK GROUP FOR UNSYMMETRICAL PLATE GIRDERS

CONSECUTIVE CHAIRMEN:

C. A. Zwissler
L. H. Daniels

MEMBERS

G. F. Fox
T. R. Higgins
B. G. Johnston
H. G. Juhl
K. H. Koopman
C. F. Scheffey